A Gas Analysis System for High Intensity Laser Systems

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Collaborators

- **Charles Cerjan, Lee Bernstein, Richard Fortner, Steve Haan, Rollin Harding, Steve Hatchett, Rob Hoffman, Ken Moody, Dawn Shaughnessy, and Dieter Schneider**

Outline of presentation

- **We have been considering several nuclear reactions for both diagnostic and scientific purposes**
  - —**Technique is broad and has more than one diagnostic use (based on a variety of nuclear reactions)**
  - —**This is a work in progress update (radchem movies being generated by Rob Hoffman and Charlie Cerjan)**
  - —**Little will be said about capsule fabrication but it is recognized as a serious issue**
- **OMEGA results**
- **Looking to the future at NIF**

Many different elements are desired for a variety of reasons

Already in capsules!

Only a few of these elements are routinely doped into capsules (e.g. Br, Ti, Ge, Cu …)

List of Desired Elements for NIF capsules

Element	Measured Isotope	Capsule location	Purpose	Priority	Priority codes	
					1	V. High
^{18}O	^{21}Ne	Inner ablator or shell, outer DT ice	Mix/Charged particle	1	2	High
Ar	^{37}Ar	DT gas or ice	High energy neutrons	1	3	Medium
Be	^{10}Be	Ablator	Low energy neutrons	1	4	Low
Br	^{79,81}Kr	Inner ablator or shell	Mix/Charged particle	1		
Cu	^{62,64}Cu	Ablator	Spectral/capture	1		
Kr	^{79,81}Kr	DT gas or ice	Spectral/capture	1		
Nb	^{91,92m,93m,94m}Nb	Inner ablator or shell, outer DT ice	Spectral/capture	1		
Ne	^{21}Ne	DT gas or ice	High energy neutrons	1		
Ti	^{48}V	Inner part of ablator or inner shell	Mix/Charged particle	1		
Xe	^{125,127,129m,131m,133,135}Xe	DT gas or ice	High energy neutrons	1		
Y	^{86,87,88}Y	Inner part of ablator, CH foam in Double Shell	High energy neutrons	1		
^{7}Li	^{7}Be	DT fuel	Charged particle	2		
Ag	^{106m}Ag	Inner ablator or shell, outer DT ice	High energy neutrons	2		
As	^{71,72,73,74,76,77}As	Inner ablator or shell, outer DT ice	Spectral/capture	2		
Au	^{193,194,196,198}Au	Inner ablator or shell	Spectral/capture	2		
Bi	^{207,208,210}Bi	Inner ablator or shell, outer DT ice	Spectral/capture	2		
Cl	^{34m,36}Cl, ^{37}Ar	Inner ablator or shell, outer DT ice	Mix/Charged particle	2		
Cr	^{52}Mn	Inner ablator or shell, outer DT ice	Mix/Charged particle	2		
Eu	^{148,149,150,152}Eu, ^{151,153}Gd	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	2		
I	^{124,125,126,128}I, ^{127}Xe	Inner ablator or shell, outer DT ice	Mix/Charged particle	2		
Re	^{183,184}Re, ^{185}Os	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	2		
Zr	^{87,88,89}Zr	Inner ablator or shell, outer DT ice	High energy neutrons	2		
Hf	^{175,178m,179m,180m}Hf	Inner ablator or shell, outer DT ice	Spectral/capture	3		
Lu	^{169,170,171,172,173,174}Lu	Inner ablator or shell, outer DT ice	Spectral/capture	3		
Mo	^{93,99}Mo, ^{96,97}Tc	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	3		
Nd	^{140,141,147,149}Nd, ^{148,149}Pm	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	3		
Ni	^{56,57}Ni	Inner ablator or shell, outer DT ice	High energy neutrons	3		
Rh	^{99,100,101,102}Rh	Inner ablator or shell, outer DT ice	High energy neutrons	3		
Ta	^{179,182,183}Ta	Inner ablator or shell, outer DT ice	Spectral/capture	3		
Tl	^{199,200,201,202,204}Tl	Inner ablator or shell, outer DT ice	Spectral/capture	3		
Tm	^{166,167,168,170}Tm	Inner ablator or shell, outer DT ice	Spectral/capture	3		
W	^{181,185,187}W	Inner ablator or shell, outer DT ice	Spectral/capture	3		
Ir	^{187,188,189,190,192,193m,194,195}Ir, ^{191,193m,195m}Pt	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	4		
Rb	^{83,84,86}Rb	Inner ablator or shell, outer DT ice	Spectral/capture	4		
Sm	^{145,151,153}Sm, ^{147,148,149,150,152}Eu	Inner ablator or shell, outer DT ice	Spectral/Mix/Charged particle	4		

# We have been investigating the following radiochemical signatures

- **Implosion asymmetry – Sc, Ir, Xe (n,2n) (n,γ)**

- **Mix – ^{18}O(α,n)^{21}Ne, Br(d,2n) and Br(p,n)**

- **Ion temperature (fuel ρR) – Kr, Ar (n,2n)**

- **dE/dx – O**

- **Influence of isomeric states**

The various nuclear reactions used for radiochemistry utilize a variety of neutron and charged particle reactions

A significant difference exists between a working capsule and a failing capsule

Material Density Snapshot
Negative P_6 Failure

Failure   **1 MJ Yield**

Shell and Fuel
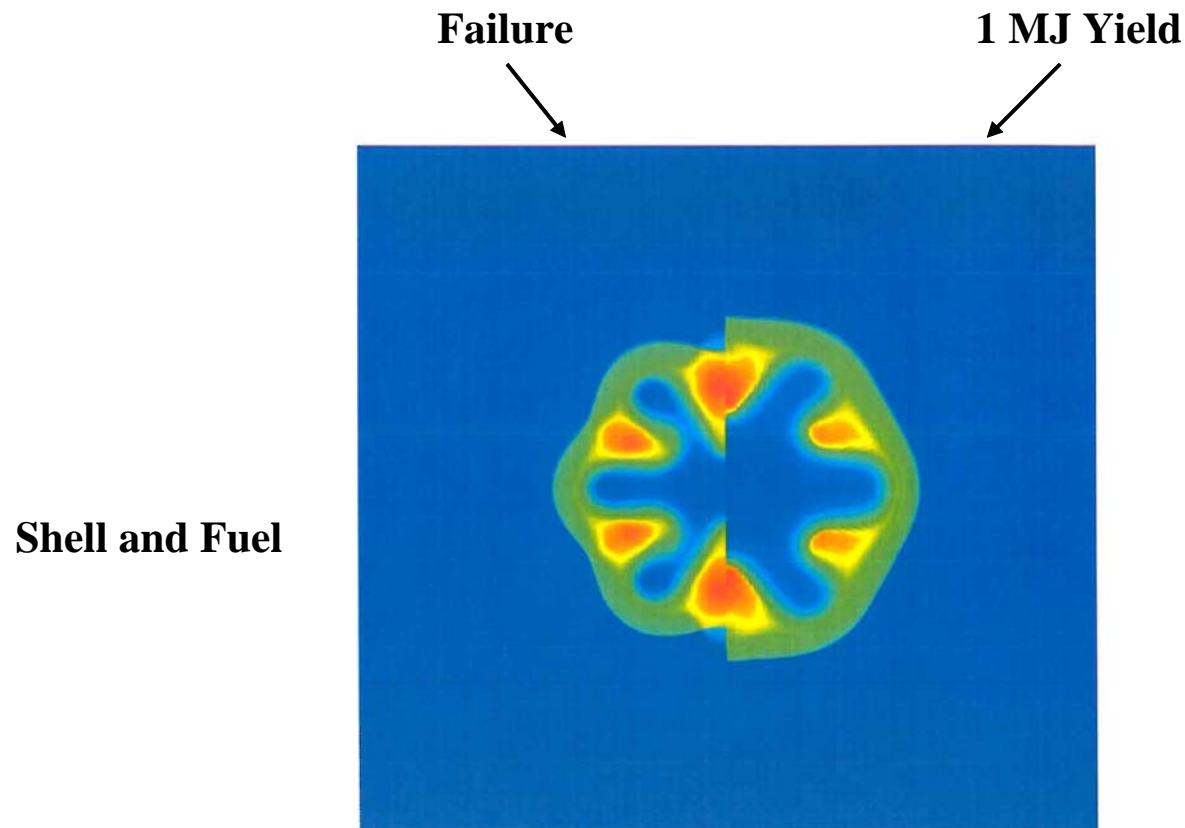
Cerjan

For asymmetry and mix, we position the dopant in the inner part of the ablator
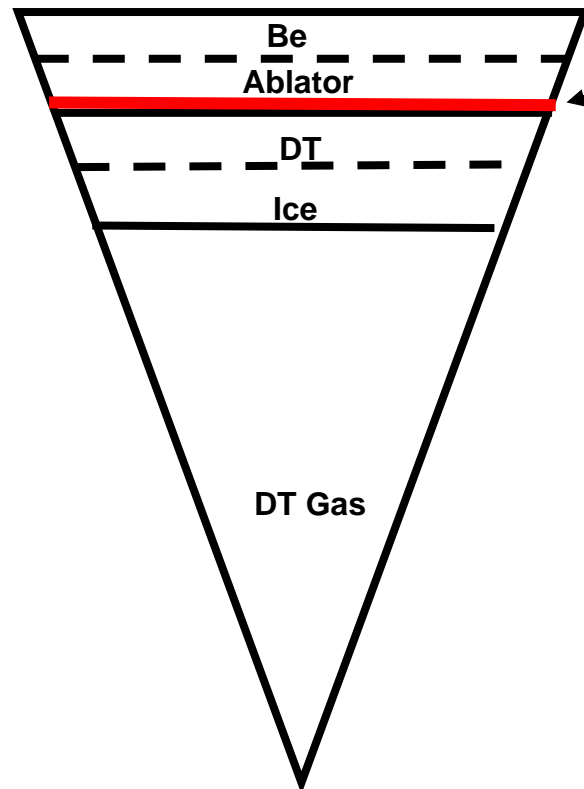
Radiochemical dopant

Be

Ablator

DT

Ice

DT Gas

- The inner part of the ablator is not blown off during the compression phase of the implosion

- This location is ideally suited to investigate ablator/fuel mix and is very near the high fluence region of the capsule

- We have investigated spatial loadings of dopants for one asymmetry mode (P6), but signal is just as robust with symmetric loadings (for those asymmetries investigated (P6 and P4)

- Amounts of dopant are low enough to not affect the implosion (for this location) and are on the order of $1{\times}10^{14} - 1{\times}10^{15}$ atoms

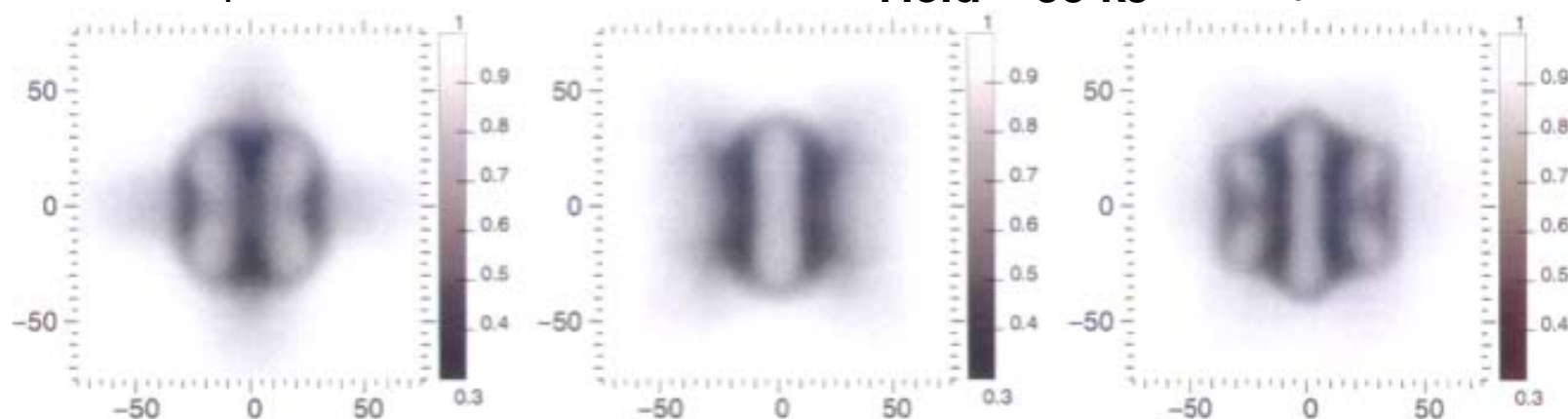# Rogues gallery of ARC radiographs of "hard" failures at bang time:(typically Y<~ 50 kJ)

-P$_4$ **+P$_4$**   **Yield = 33 kJ**   **-P$_6$**   **Steve Hatchett**

^{135}Xe/^{133}Xe = 1.84×10^{-3} ^{135}Xe/^{133}Xe = 2.26×10^{-3}

P4/P6 = 0.81

+P$_6$ **+P$_{10}$**   P1-   **P$_{1-20}$**
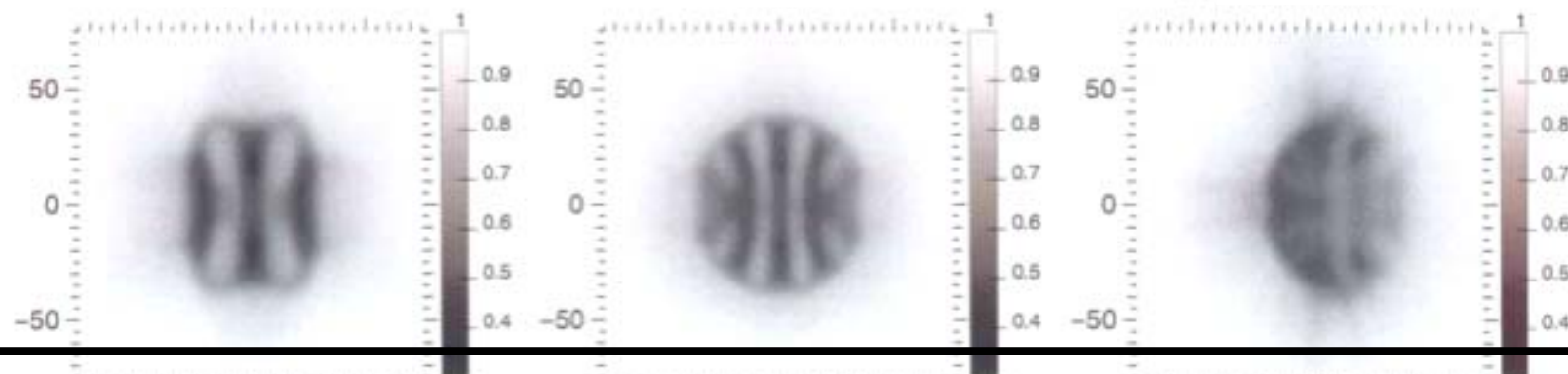
Both (n,γ) reactions and (n,2n) reactions show significant signals

Only subtle features may distinguish a +P$_4$ drive asymmetry from -P$_6$, at the same yield (1 MJ below). Compton radiographs may prove very useful.
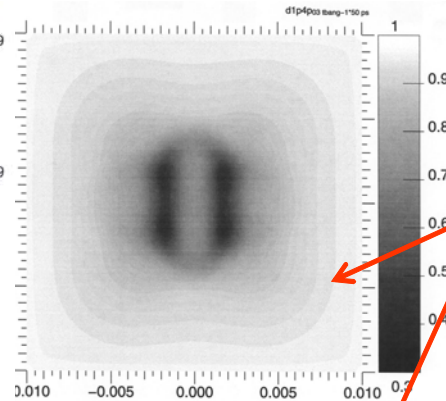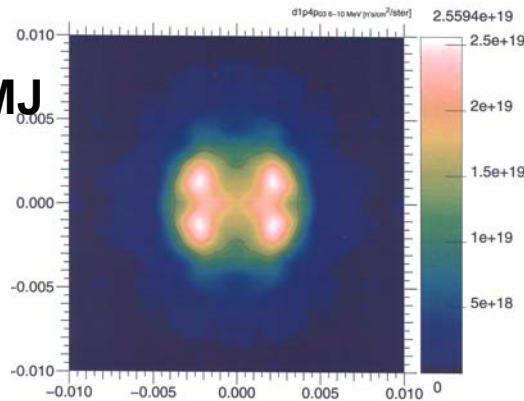
6-10 MeV neuts   **Compton radiograph**   **Steve Hatchett**
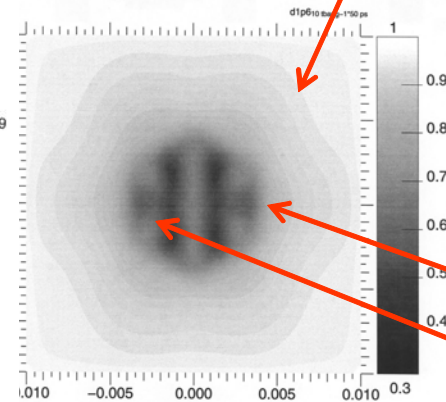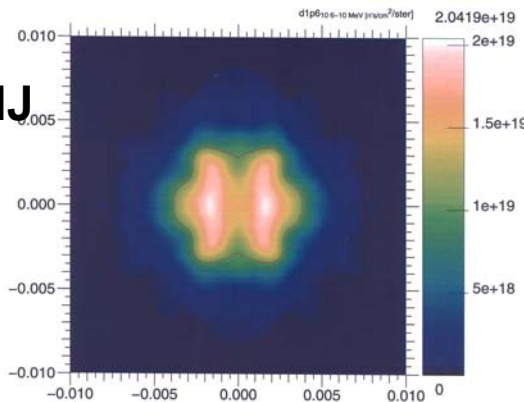

Yield = 1.2 MJ

+1.9% P4

^{135}Xe/^{133}Xe = 1.40×10^{-3}

Compare shapes of *high* transmission contours. (*Low* contours of primary neut. image have same info.)
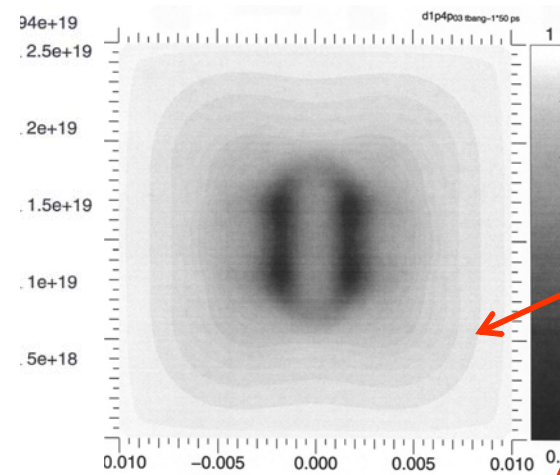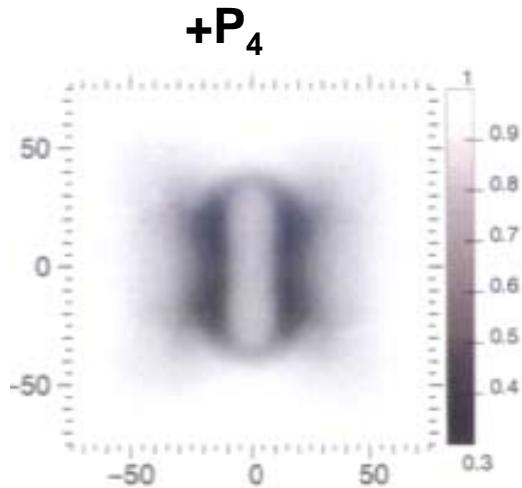
Yield = 0.88 MJ

-0.97% P6

^{135}Xe/^{133}Xe = 1.43×10^{-3}

Shadows of polar blobs

Dividing each ratio by the yields, the P4/P6 activation ratio = 0.71

For completeness sake, comparison of failures to successes

Steve Hatchett

+P_4

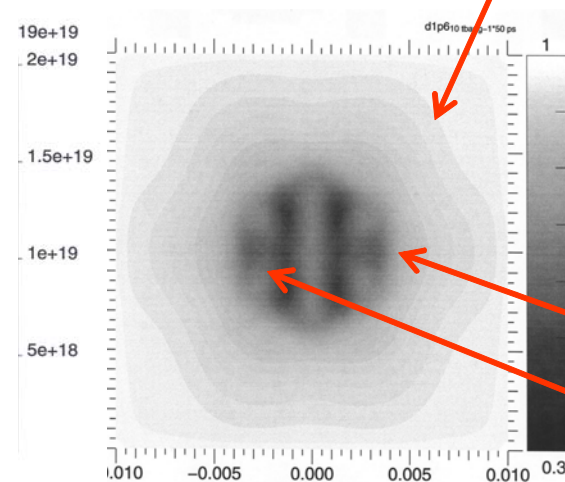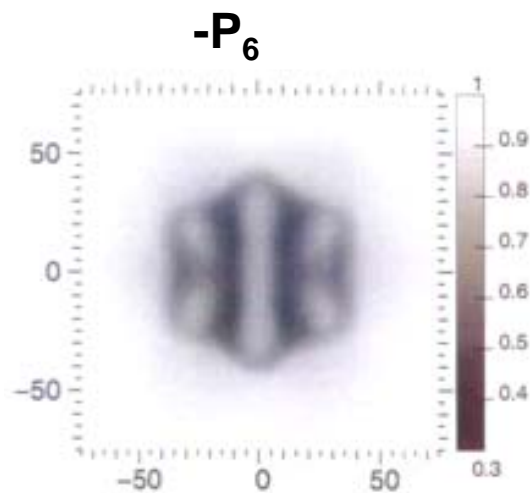P_4 failure has a drop of a factor of 37 in yield, but $^{135}Xe/^{133}Xe$ ratio increases by 31%

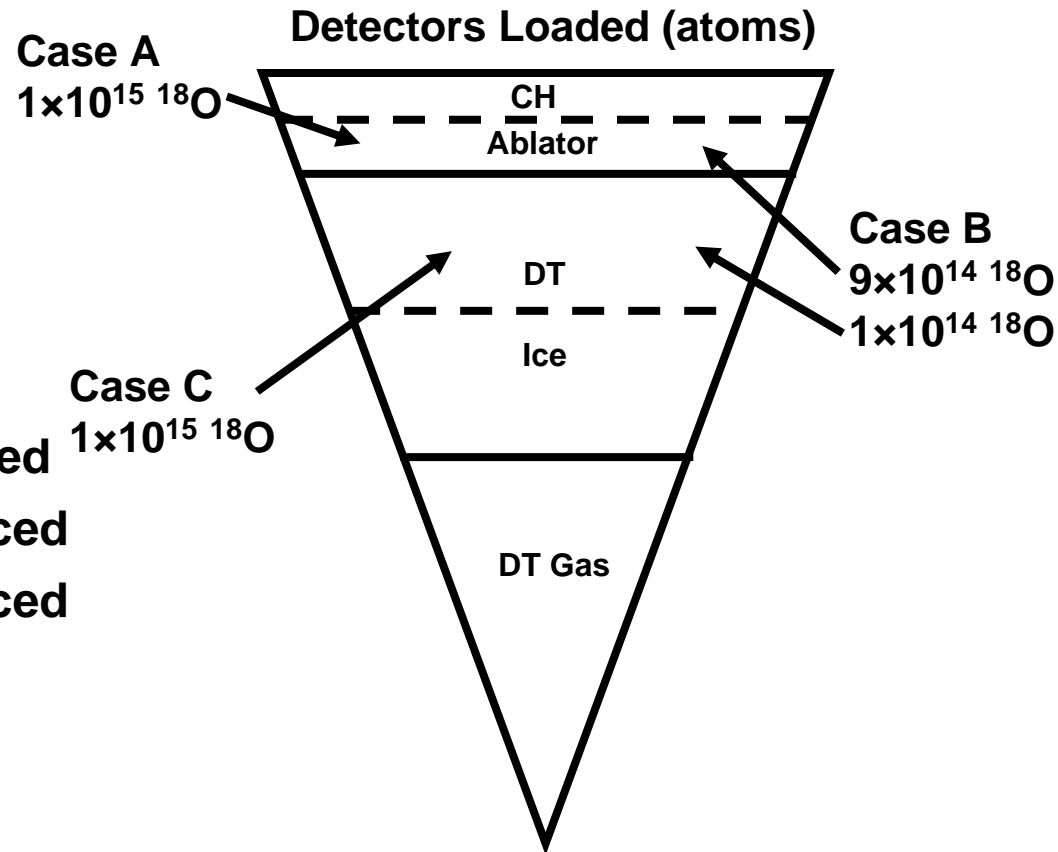# Comparison of failures to successes

Steve Hatchett

-P$_6$

P$_6$ failure has a drop of a factor of 26 in yield, but ^{135}Xe/^{133}Xe ratio increases by 58%

Charged-particles can be used to quantify the amount of ablator/fuel mix

- **Yield = 16 MJ**

- **175 Group n/30 group CP**

- **Reaction is $^{18}O(\alpha,n)^{21}Ne$**

- **Need $10^4 - 10^6$ atoms ^{21}Ne for measurement**

- **Case**

  A. 6.81×10^9 atoms ^{21}Ne produced

  B. 4.23×10^{10} atoms ^{21}Ne produced

  C. 3.61×10^{11} atoms ^{21}Ne produced

- **Production of ^{21}Ne sensitive to "mix" and measurable**

Detectors Loaded (atoms)

Case A
1×10^{15} ^{18}O

CH

Ablator

Case B
9×10^{14} ^{18}O
1×10^{14} ^{18}O

DT

Ice

Case C
1×10^{15} ^{18}O

DT Gas

Charged-particle reactions valuable for diagnosing "mix"

Charged particle reactions distinguish between two cases where cracks exist in the DT ice

Be

Ablator

DT

Ice

DT Gas
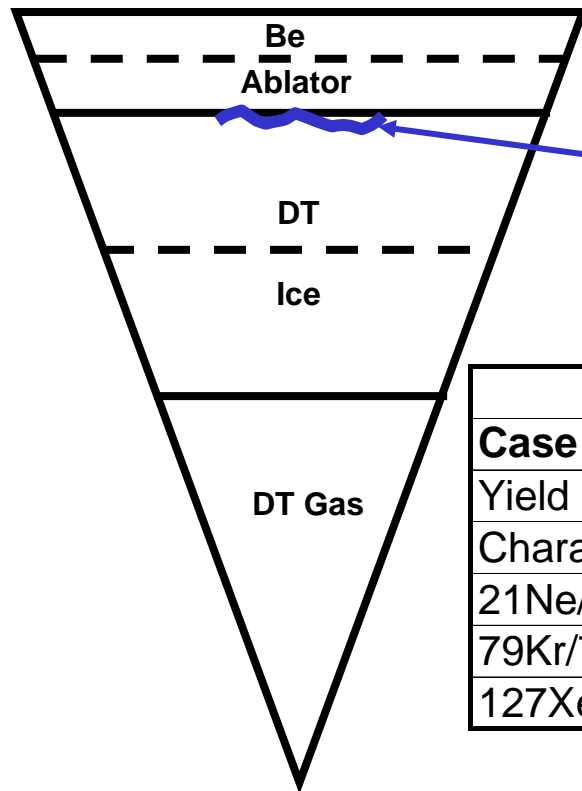
Case A (small crack)

Cerjan

Case B (larger crack)

Case	A	B	
	ic00	**ic01**	Percentage increase
Yield (MJ)	1.27891	0.12648	over yield scaling
Characteristic	sm. Crack	lg. Crack	(B-A/(YA/YB))/B
21Ne/18O	9.88E-10	1.90E-10	49%
79Kr/79Br	3.75E-10	3.49E-09	99%
127Xe/127I	3.21E-10	2.64E-09	99%

Fuel ρR measurements are feasible with ^{38}Ar doped OMEGA DT capsules

Ablator

DT fuel
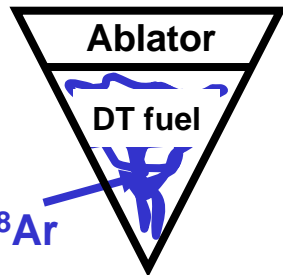
^{38}Ar

Reaction Used
^{38}Ar(n,2n)^{37}Ar

^{37}Ar has a 35 d half-life and is measured by gas-proportional counting (MDA ≈ 4 × 10^5 atoms)

Below MDA!

Capsule	Ablator	Yield (14 MeV neutrons)	Fuel ρR (mg/cm^2)	^{37}Ar/^{38}Ar*	K‡ (× 10^{23})
ID	glass	6.0×10^9	-	1.2×10^{-10}	-
DD Cryo	CH	$\sim 10^{14}$	-	3.8×10^{-9}	-
DD Non-Cryo	glass	3.2×10^{13}	6.6	1.1×10^{-8}	5.4
DD Non-Cryo†	glass	3.9×10^{13}	6.8	1.4×10^{-8}	5.4
DD Non-Cryo	CH	6.7×10^{12}	13.8	5.7×10^{-9}	6.2
DD Non-Cryo	CH	9.1×10^{12}	14.6	8.2×10^{-9}	6.2

* ~1 at% ^{38}Ar loaded in fuel region of capsule

† Significant production of ^{38}Cl, ^{35}S, and ^{39}Ar also

‡ K = (^{37}Ar/^{38}Ar)/(Y·ρR)

1D Lasnex simulations of direct-drive OMEGA DT capsules indicate ^{37}Ar activation is proportional to fuel ρR and measurable

Radiochemistry provides unique signals distinguishing twelve "benchmark" calculations

		means one product is below 1E6 atoms with this detector loading						
					ARC images are available from SH presentation			
			Ice crack	Ice crack	ARC	ARC	ARC	ARC
		ID	ic00	ic01	sh00	sh01	sh02	sh03
		Yield (MJ)	1.27891	0.12648	0.87705	0.0339743	1.21456	0.0330379
Loaded	No. Loaded	Characteristic	sm. Crack	lg. Crack	P6 -0.0097	P6 -0.0145	P4 0.0190	P4 0.0285
18O	2.672E+15	21Ne/18O	9.88E-10	1.90E-10	1.59E-07	1.72E-09	5.74E-07	1.71E-09
79Br	5.069E+13	79Kr/79Br	3.75E-10	3.49E-09	7.57E-07	9.99E-09	1.21E-06	1.14E-08
127I	1.000E+14	127Xe/127I	3.21E-10	2.64E-09	5.44E-07	7.27E-09	8.99E-07	8.41E-09
134Xe	2.580E+13	135Xe/133Xe	7.03E-04	2.23E-03	1.43E-03	2.26E-03	1.40E-03	1.84E-03
		133Xe/134Xe	2.62E-07	3.80E-06	9.66E-04	2.53E-05	1.42E-03	3.02E-05
		135Xe/134Xe	1.77E-10	8.48E-09	1.38E-06	5.71E-08	1.99E-06	5.57E-08
		127Xe/125Xe					2.39E-02	3.52E-02
		(135Xe/133Xe)fail/good		3.18		1.58		1.31

	Cerjan Asymmetry -->					
ID	ir01	ir02	ir03	ir04	ir05	ir06
Yield (MJ)	1.096	0.0609	0.129	1.857	0.155	0.0623
Characteristic	P6 -0.0053	P6 -0.00795	P6 -0.0066	P4 -0.0115	P4 -0.014375	P4 -0.01725
21Ne/18O	2.12E-07	4.50E-09	1.33E-08	6.52E-07	1.72E-08	4.69E-09
79Kr/79Br	1.03E-06	2.02E-08	5.44E-08	2.16E-06	7.30E-08	2.26E-08
127Xe/127I	7.40E-07	1.45E-08	3.69E-08	1.60E-06	5.20E-08	1.63E-08
135Xe/133Xe	1.32E-03	2.06E-03	1.84E-03	1.32E-03	1.74E-03	1.88E-03
133Xe/134Xe	1.18E-03	5.38E-05	1.36E-04	1.93E-03	1.73E-04	5.83E-05
135Xe/134Xe	1.57E-06	1.11E-07	2.50E-07	2.54E-06	3.00E-07	1.09E-07
127Xe/125Xe						
(135Xe/133Xe)fail/good		1.56	1.39		1.32	1.42

Comparing deuteron induced reactions with alpha induced reactions enables clear distinction between several of the "benchmark" calculations

Charged particle
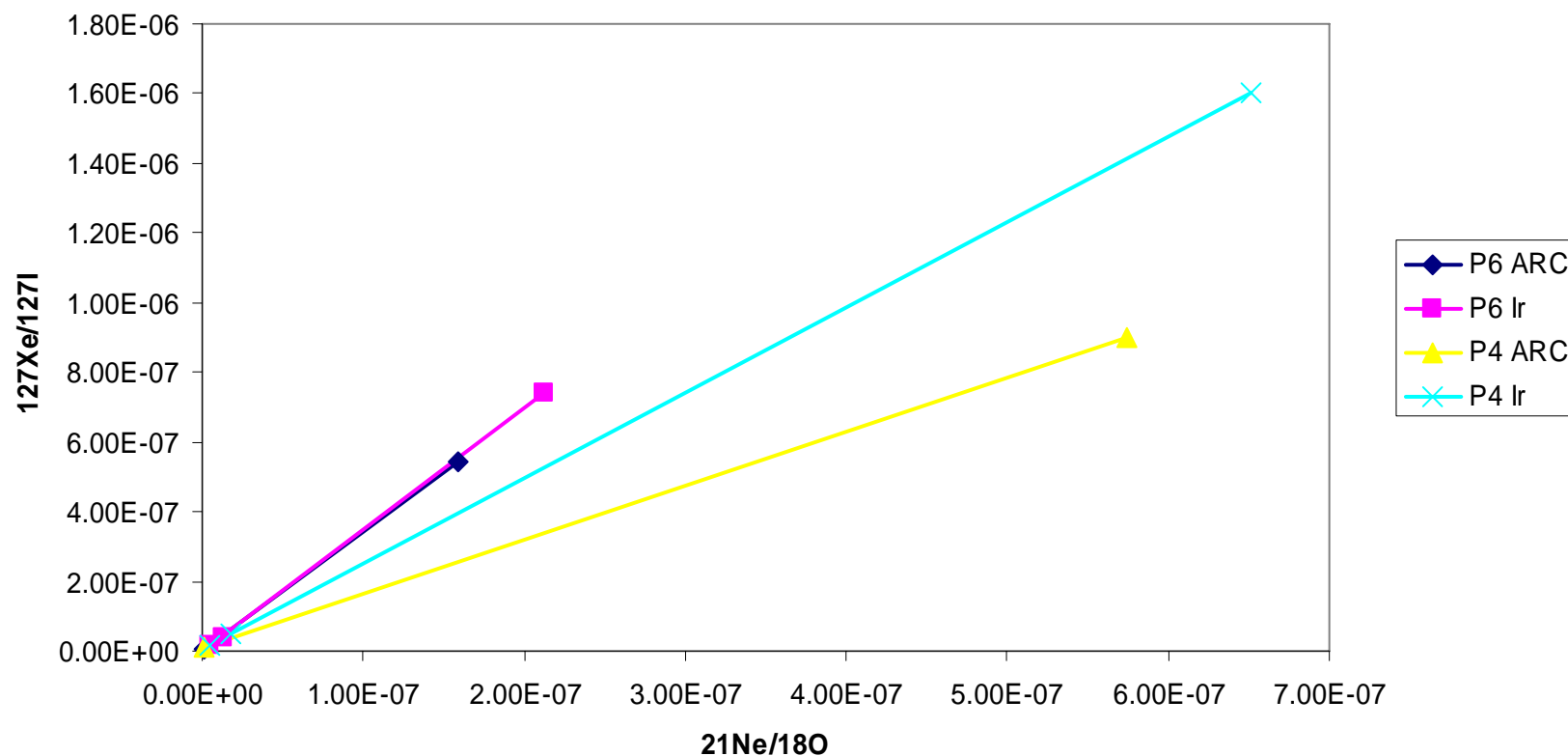
Why gas sampling?

- **Gas collection may be nearly 100% efficient for collecting samples**

- **Method is chemically inert, low sorption and has low backgrounds**

- **Method could be adapted for collection of "solid" samples with the use of carrier gas**

- **In a NIF sized target chamber (10 m diameter) using a thermalized source of gas and 15 cm diameter collection port, a simple model indicates 99% collection in about 93 seconds**

- **Many charged particle reactions produce noble gas products**

- **Method is relatively insensitive to EMP or x-rays, except for the past debris blown off the target chamber walls**

- **Choice of radioactive products makes detection easier and backgrounds from other shots less (if half-life is convenient, then past production nuclides have decayed away)**

- **Method can be non-intrusive to main experimental goals**

**There are many reasons gas sampling makes sense**

- A capsule filled with a mixture of noble gases was imploded with full energy on OMEGA (3/04)

- Gas samples were taken with the OMEGA Gas Sampling System (OGSS)

- **Collection efficiencies of 84%, 75% and 107% were measured using noble gas mass spectrometry here at LLNL for Ne, Kr and Xe, respectively** (note: there is a few percent error in the measurement and the initial amounts of gases in the capsule were estimates)

- There are non-atmospheric sources of He and Ar present in the OMEGA target chamber (He is used a lot in capsules as a fuel and Ar is used to regenerate the cryopumps—not too surprising)

- Tritium background in the samples is less than 1 pCi due to the inclusion of a chemical getter pump on the system

- OGSS was used for the second time in Oct. 2004 to collect He samples and measure that collection efficiency
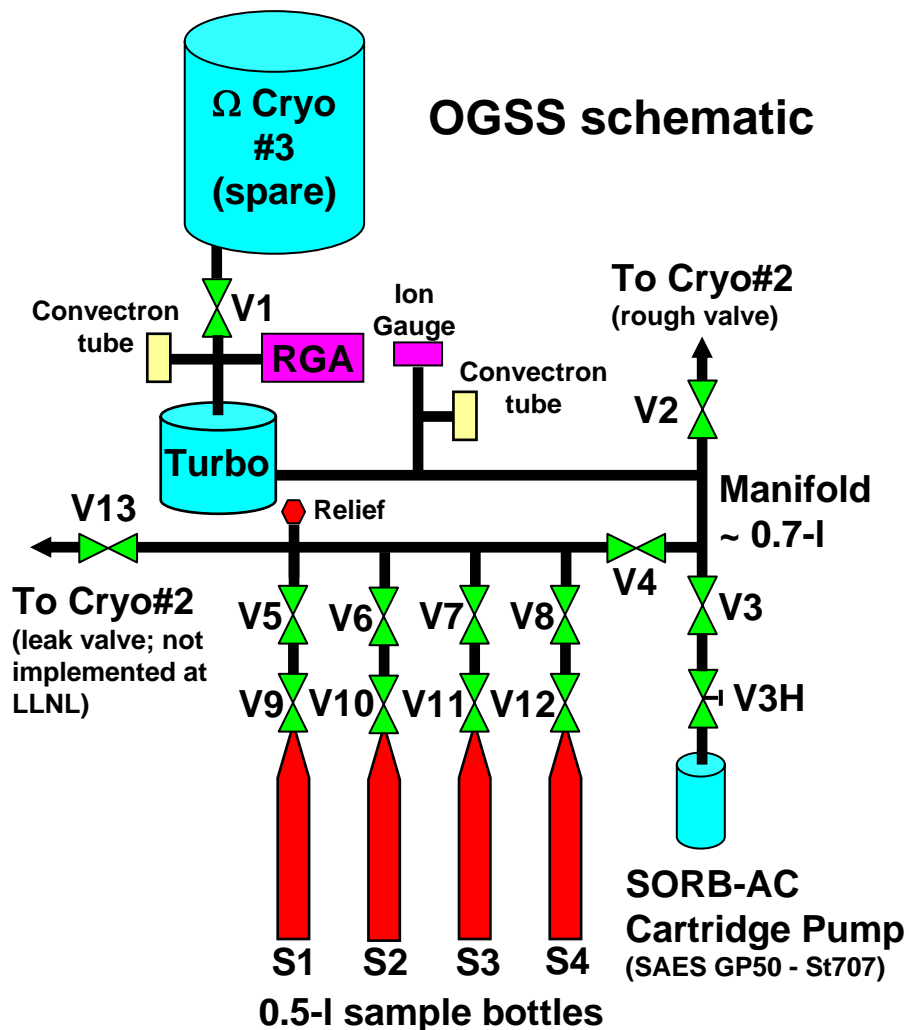
OGSS on OMEGA target chamber
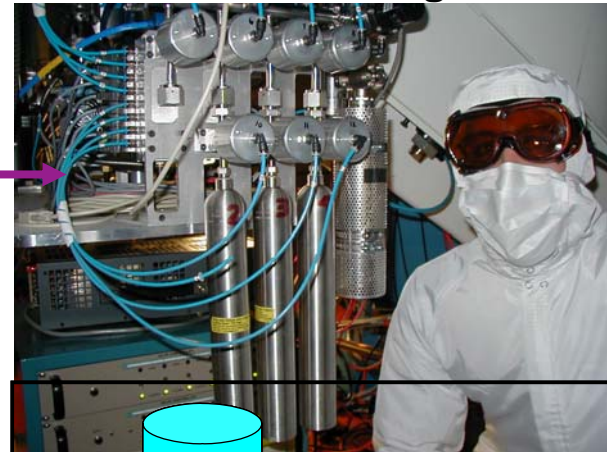
OGSS schematic
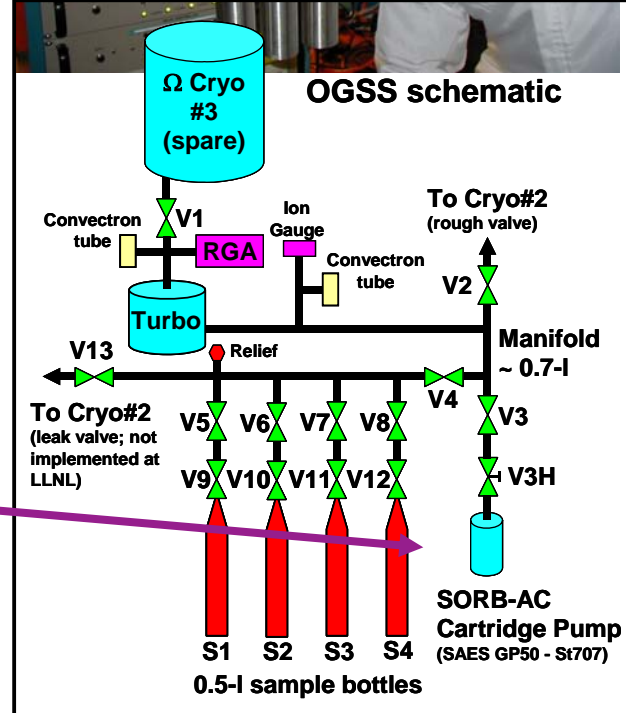
A prototype system, designed and tested at LLNL, is installed on OMEGA

OGSS schematic

The use of a **chemical getter pump** solves several problems:

- High efficiency for hydrogen
- Does not pump Noble gases
- No mechanical vibration
- Pumping speed adequate to back turbo
- Exceptionally high capacity
- Relatively inexpensive

The sample bottles use standard mass spec system fittings

Once under vacuum, requires only occasional "assistance" from cryo #2 to maintain high vacuum in the manifold and sample bottles

Gas release curves from the cryo pump show the expected sample gases and a small air leak

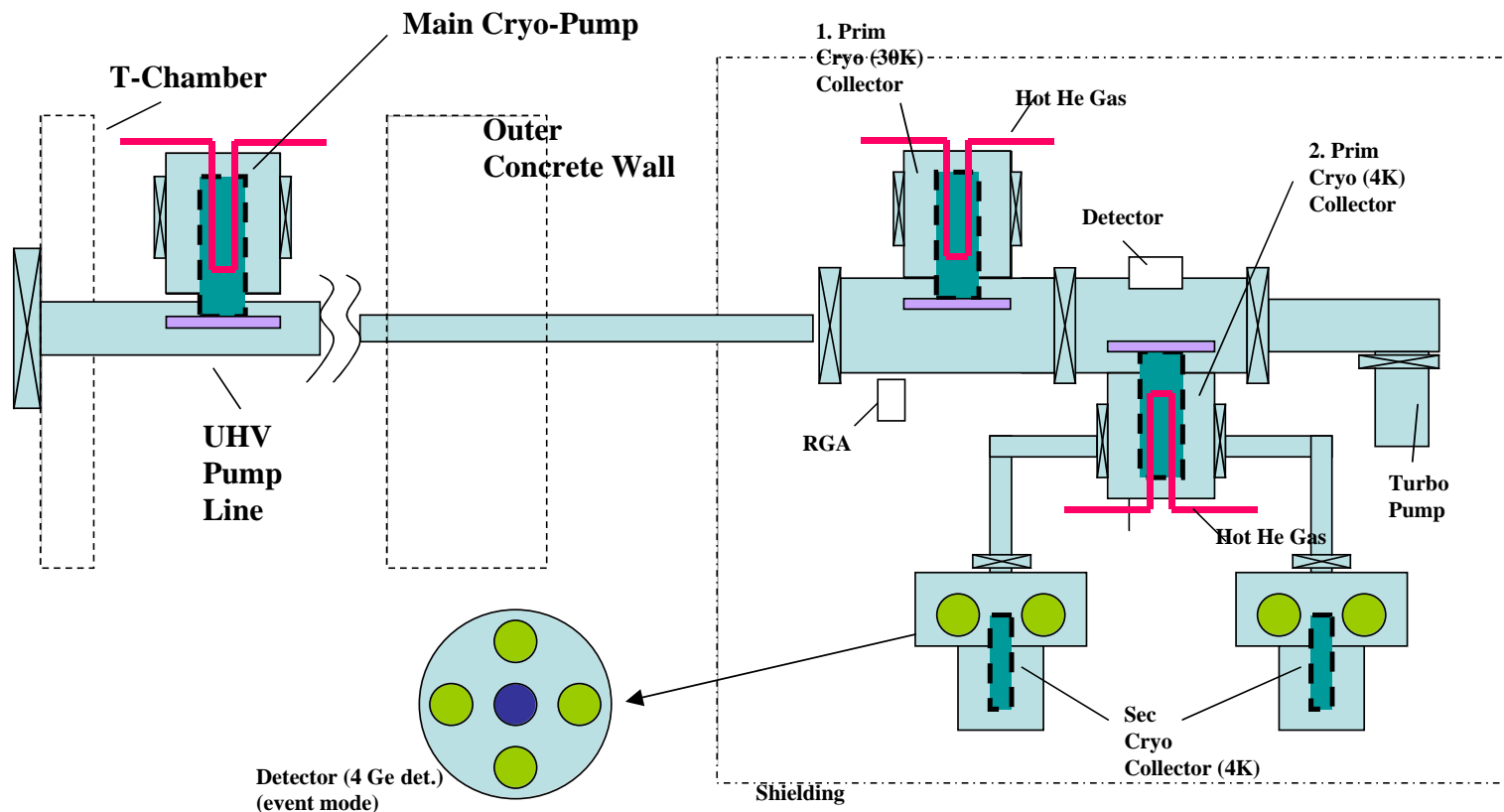**Most of the Noble gases are released well before the cryo reaches room temp**

Sangster, et al.
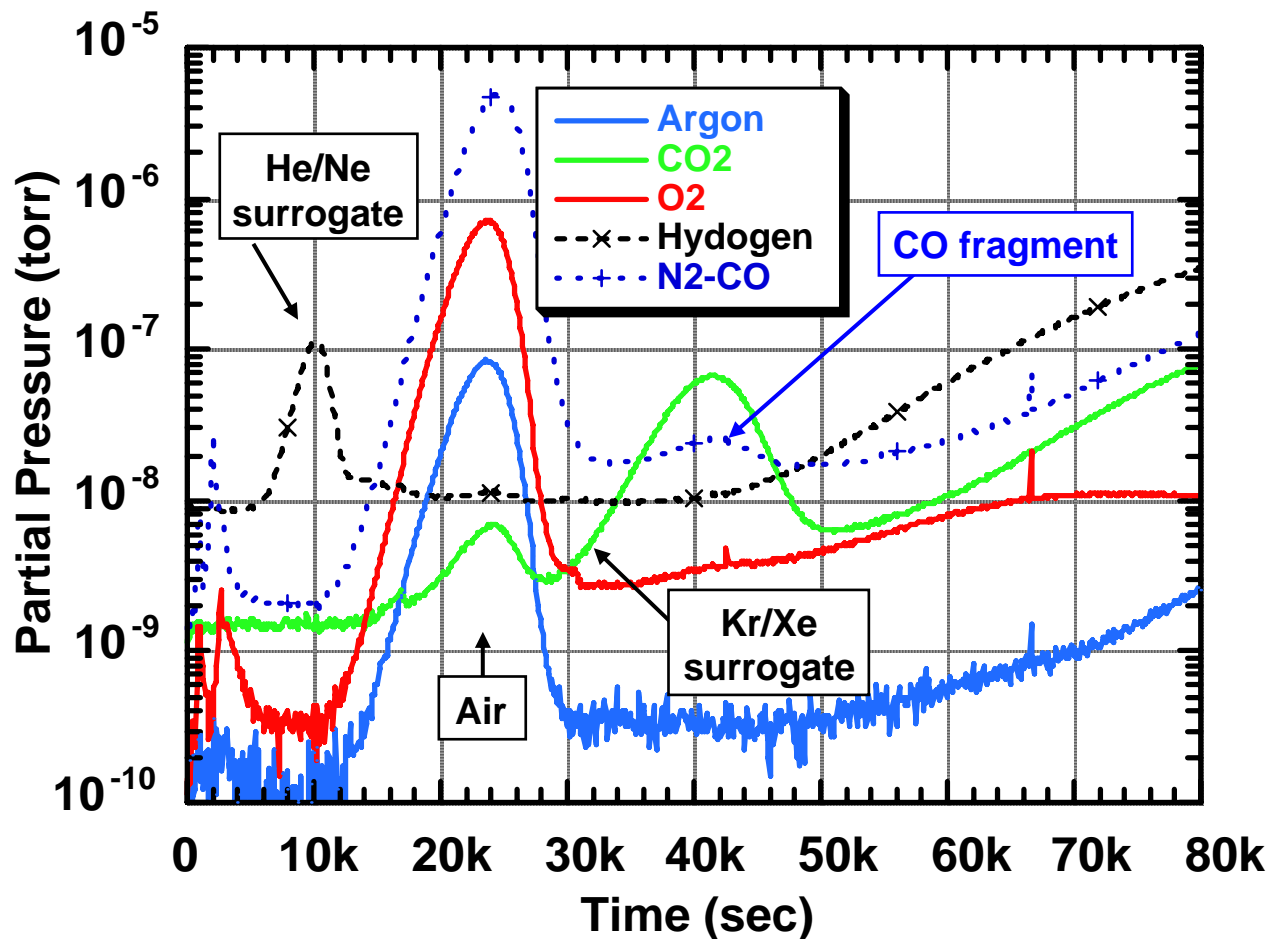
The data indicate ~100% cryo release and a consistent manifold collection efficiency

Sample #	He (std-cc)	Ne (std-cc)	Ar (std-cc)	Vacuum time
blank	1.164 (too high)	0.291	0.093	77 hrs
	f_{He} (of sample)	f_{Ne}	f_{Ar}	
1 (1.03 std-cc air)	0.747	0.519	0.464	25 hrs
2 (1.04 std-cc air)	2.756	1.026	0.674	168 hrs
3 (1.04 std-cc air)	0.972	0.590	0.500	52 hrs
4 (1.01 std-cc air)	0.762	0.513	0.465	26 hrs
5 (1.08 std-cc air)	1.288	0.666	0.532	72 hrs
6 (1.08 std-cc air)	0.956	0.567	0.487	40 hrs

Correction for an _assumed_ constant leak rate from the blank sample

1	0.381	0.427	0.435
2	0.320	0.414	0.479
3	0.218	0.400	0.440
4	0.374	0.415	0.434
5 (spiked w/^{22}Ne)	0.245	0.406	0.449
6 (spiked w/^{22}Ne)	0.377	0.422	0.441
Ave	0.314	0.422(.009)	0.441(.010)

Using the ^{22}Ne spiked samples (5 & 6), a definitive collection fraction can be determined assuming 100% release from the cryo pump:

5	0.417	**Calculated from the initial and final $^{22/20}$Ne**
6	0.418	**fractions**

Estimated collection fraction from measured manifold and sample bottle volumes: 0.43
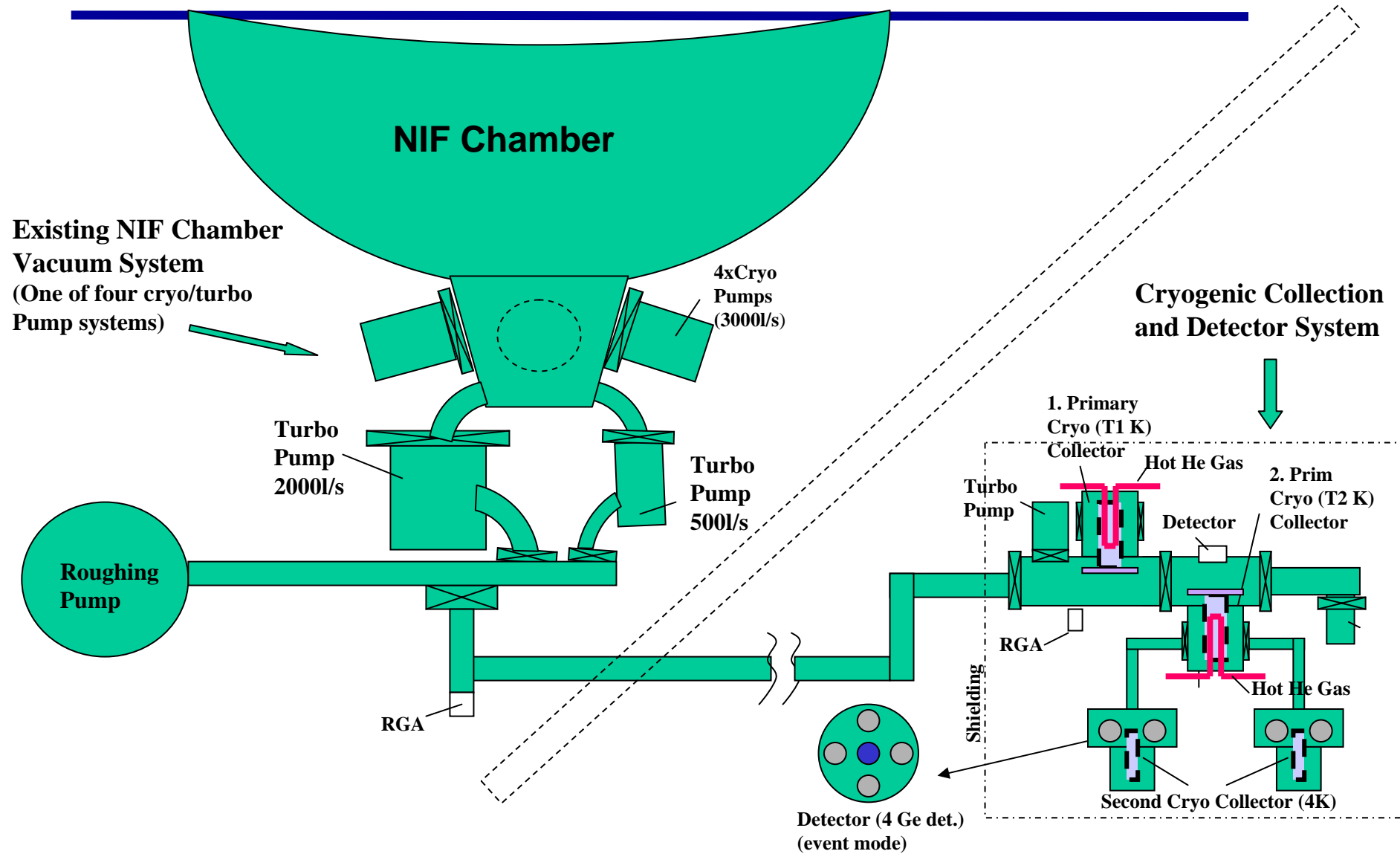
Hudson, et al.

Only some preliminary ideas have been thought about for gas collection at NIF

Dedicated Radchem Gas Collection System at NIF

Wolfgang Stoeffl

Main Cryo-Pump

T-Chamber

Outer Concrete Wall

1. Prim Cryo (30K) Collector

Hot He Gas

2. Prim Cryo (4K) Collector

Detector

UHV Pump Line

RGA

Turbo Pump

Hot He Gas

Sec Cryo Collector (4K)

Detector (4 Ge det.) (event mode)

Shielding

Proposed "Radchem" Gas Collection System using the existing NIF Chamber Vacuum System

NIF Chamber

Existing NIF Chamber Vacuum System
(One of four cryo/turbo Pump systems)

4xCryo Pumps (3000l/s)

Turbo Pump 2000l/s

Turbo Pump 500l/s

Roughing Pump

RGA

Cryogenic Collection and Detector System

1. Primary Cryo (T1 K) Collector

Hot He Gas

2. Prim Cryo (T2 K) Collector

Turbo Pump

Detector

RGA

Shielding

Hot He Gas

Second Cryo Collector (4K)

Detector (4 Ge det.) (event mode)

Significant sample analysis capability exists at LLNL

- **Low level counting facility in B151 (gamma, beta and alpha counting)**
- **Chemistry laboratories**
- **ICP-MS capability in B151**
- **Noble gas mass spectrometry (needs revival)**
- **IsoProbe**
- **Nano-Sims**
- **CAMS**
- **Activation counting at NIF**

Conclusions

- **Nuclear reactions probe important plasma physics issues such as mix—in fact there are several reactions that will be effective**

- **Radiochemical signatures for one asymmetry failure mode have been demonstrated with uniform detector loading in the innermost part of the ablator (so far spatial loading not required)**

- **Mix simulations show sensitivity to ice crack (charged particle reactions)**

- **High noble gas collection efficiencies (>80%) have been demonstrated for the first time on large laser systems**

- **NIF radiochemistry systems are starting to be designed**

Radiochemistry will provide important complimentary diagnostic information as well as enable nuclear science experiments at NIF
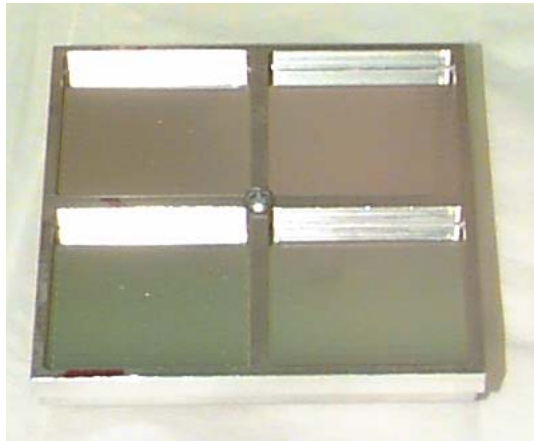
Spare viewgraphs

We are developing multiple collection schemes for retrieval of solid samples

Conical

Flat

- **Ge samples were collected with Al-covered flat and conical collectors positioned so that approximately equal solid angles were subtended**

- **Ge/Al separation chemistry will be performed**
  - **Dissolve Al foils with 2M HF**
  - **Load samples in 12M HCl on DOWEX-1×8 anion exchange columns**
  - **Remove Al with 12M HCl**
  - **Elute Ge with 2M HCl**
  - **^{68}Ge used as tracer ($t_{1/2}$ = 270.8d; detect 1077.3 keV gamma-ray from daughter 1.130h ^{68}Ga)**

- **The IsoProbe mass spectrometer will be used to measure isotopics and amount of Ge in the chemical samples**

A comparison of Ge collection efficiencies will be made for two collectors once the Ge chemistry is tested

Sc and Ir radiochemistry results

Isotope	1 MJ	50 kJ	50 kJ/1 MJ	atoms/yield	Signal	50 kJ/MNA
45Sc	9.99E+13	1.00E+14	1.00E+00	1.86E+01	1759.49%	
46Sc	1.21E+08	1.51E+07	1.25E-01	2.32E+00	131.82%	1.89E+00
43Ca	1.26E+07	3.90E+04	3.10E-03	5.75E-02	94.25%	
41K	1.03E+06	3.40E+03	3.30E-03	6.13E-02	93.87%	
43Sc	1.39E+06	5.21E+03	3.75E-03	6.96E-02	93.04%	8.68E-03
45Ti	2.40E+07	5.06E+05	2.11E-02	3.92E-01	60.84%	3.37E-03
46Ti	8.43E+07	1.95E+06	2.31E-02	4.30E-01	57.03%	
44Ca	3.53E+10	1.74E+09	4.93E-02	9.16E-01	8.43%	
42K	4.66E+09	2.35E+08	5.04E-02	9.37E-01	6.32%	1.18E+03
45Ca	5.56E+09	2.81E+08	5.05E-02	9.39E-01	6.12%	2.34E+02
44mSc	8.02E+09	4.19E+08	5.22E-02	9.71E-01	2.95%	8.38E+02
44Sc	1.90E+10	1.00E+09	5.26E-02	9.78E-01	2.23%	5.00E+03

Isotope	61 kJ	1.1 MJ	61kJ/1.1MJ	atoms/yield	Signal	61 kJ/MNA
Ir	2.58E+13	2.58E+13	1.00E+00	1.80E+01	1703.28%	
194Ir	2.12E+07	1.49E+08	1.42E-01	2.57E+00	156.57%	2.12E+01
194mIr	4.41E+06	3.44E+07	1.28E-01	2.31E+00	131.18%	8.82E-01
189Ir	1.50E+05	2.04E+07	7.35E-03	1.33E-01	86.74%	2.50E-02
190Ir	8.26E+08	1.81E+10	4.56E-02	8.23E-01	17.71%	4.13E+02
192Ir	1.33E+09	2.88E+10	4.62E-02	8.33E-01	16.72%	4.43E+02
193mIr	2.48E+08	4.58E+09	5.41E-02	9.76E-01	2.36%	4.13E+01

Both (n,γ) reactions and (n,2n) reactions show significant signals

Multiple-order (n,2n) reactions can be used to measure mix in NIF capsules

Detector (atoms) or Ratio	No Mix	10% Mix of ablator/detector
$^{175}Lu_L$	1.00×10^{16}	1.00×10^{16}
^{174}Lu	1.07×10^{13}	3.60×10^{13}
^{173}Lu	1.96×10^{10}	4.50×10^{11}
^{172}Lu	3.24×10^{7}	5.10×10^{9}
^{171}Lu	4.52×10^{4}	4.79×10^{7}
^{170}Lu	4.41×10^{1}	3.35×10^{5}
$^{174}Lu/^{175}Lu_L$	1.07×10^{-3}	3.60×10^{-3}
$^{173}Lu/^{174}Lu$	1.83×10^{-3}	1.25×10^{-2}
$^{172}Lu/^{173}Lu$	1.65×10^{-3}	1.13×10^{-2}
$^{171}Lu/^{172}Lu$	1.40×10^{-3}	9.41×10^{-3}
$^{170}Lu/^{171}Lu$	9.76×10^{-4}	6.98×10^{-3}
$^{169}Tm_L$	1.00×10^{16}	1.00×10^{16}
^{168}Tm	1.04×10^{13}	3.50×10^{13}
^{167}Tm	1.87×10^{10}	4.38×10^{11}
^{166}Tm	2.90×10^{7}	4.70×10^{9}
^{165}Tm	4.11×10^{4}	4.53×10^{7}
$^{168}Tm/^{169}Tm_L$	1.04×10^{-3}	3.50×10^{-3}
$^{167}Tm/^{168}Tm$	1.80×10^{-3}	1.25×10^{-2}
$^{166}Tm/^{167}Tm$	1.55×10^{-3}	1.07×10^{-2}
$^{165}Tm/^{166}Tm$	1.42×10^{-3}	9.64×10^{-3}

Because of large 14 MeV fluence, three to four sequential (n,2n) reactions are observable in NIF experiments without mix; this increases to four to five sequential (n,2n) reactions if 10% mix

Tm similar but Lu cross-section set more developed

Lu ratios as a function of mix

Atom ratio

Mix (%)

- 174Lu/175Lu
- 173Lu/174Lu
- 172Lu/173Lu
- 171Lu/172Lu
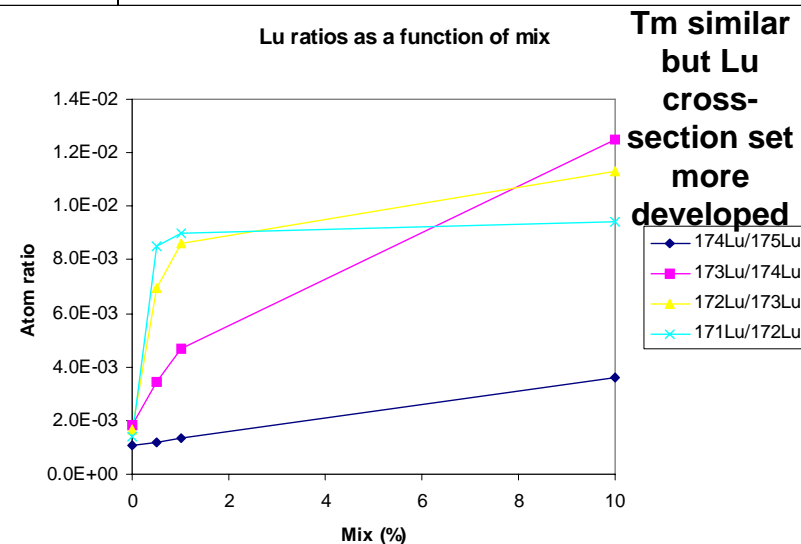
The observed isotope ratios would determine mix percentage and severely constrain models of the implosion

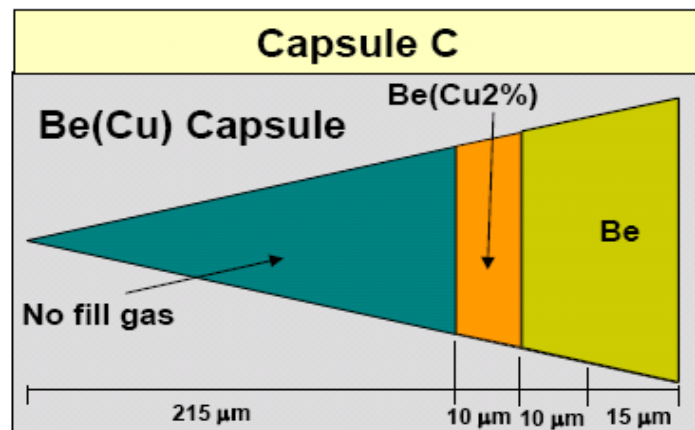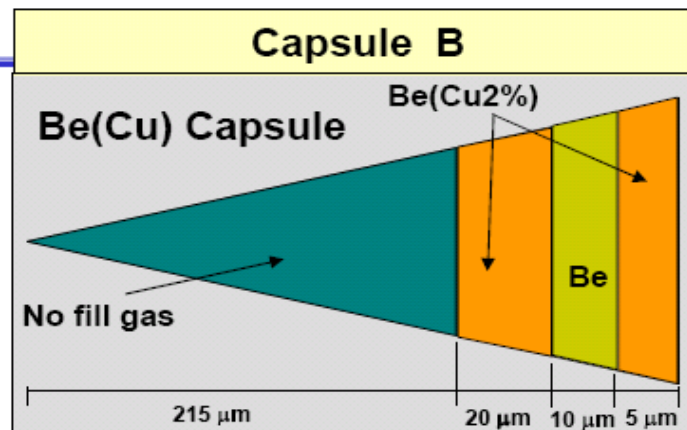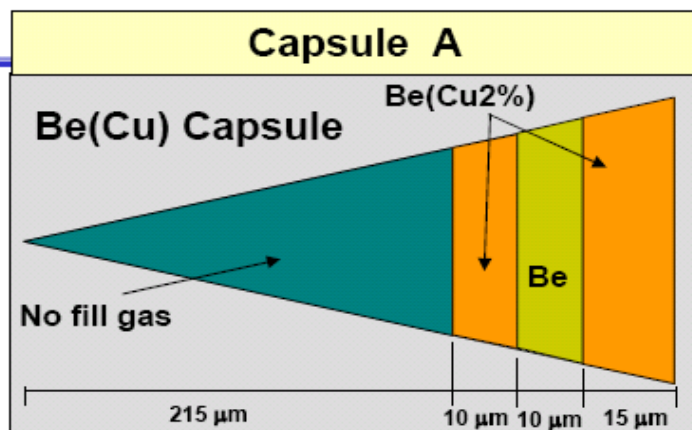# Cu activation can be used to measure the thickness of the capsule ablator at peak neutron production time

- **^{65,63}Cu present in the ablator will react with 14 MeV neutrons produced by DT fusion to produce nuclides that emit gamma-rays (^{64,62}Cu) via (n,2n) reactions—the cross-section for these reactions are large (0.5-1 b)**

- **A sample of Cu will be collected following an implosion that will include un-reacted Cu and these radioactive nuclides**

- **The radioactivity (^{64}Cu $t_{1/2}$ = 12.7 h and ^{62}Cu $t_{1/2}$ = 9.7 m) is quantified via gamma-ray spectroscopy (1345.8-keV gamma-ray and 857.7-keV gamma-ray, respectively)**

- **The Cu in the samples is chemically purified and the un-reacted Cu is quantified via isotope dilution mass spectrometry to determine the fraction of Cu collected**

Cu   30.83% ^{65}Cu
69.17% ^{63}Cu

DT

Ablator

Pre-implosion

Conical Collector

Hit with Laser

14 MeV neutrons

Conical Collector

Conical Collector

Collect Debris

Peak neutron production time

Post-implosion
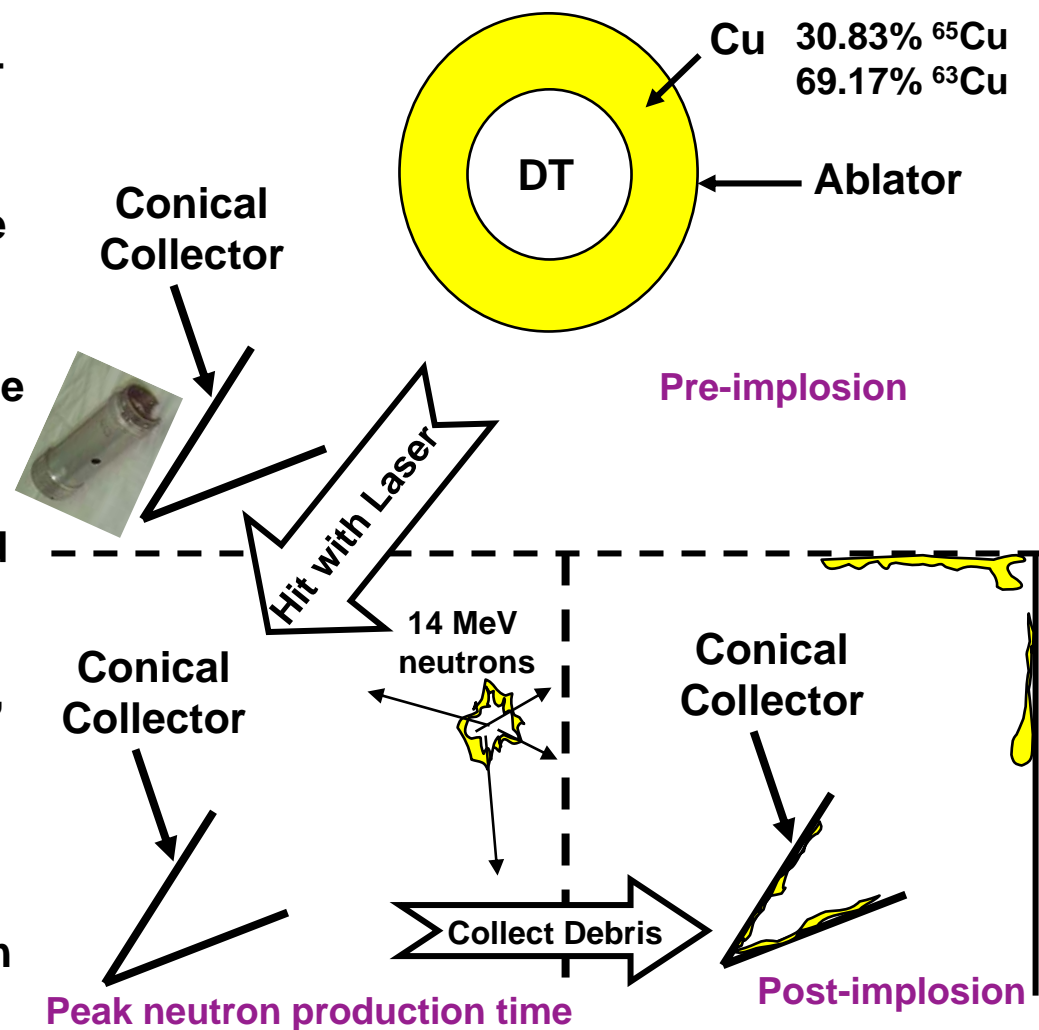
The ratio ^{64}Cu/^{65}Cu (or ^{62}Cu/^{63}Cu) is proportional to ρR × Yield

Several different targets were used for radiography -- ride-a-long collections were performed

Carol Velsko, Brian Spears, Damien Hicks, Mark Stoyer
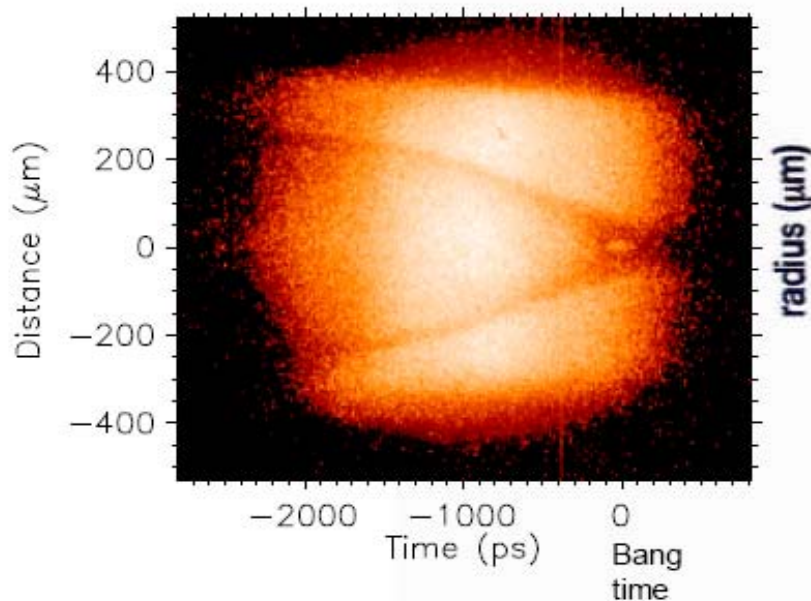
Convergent Ablation Rate Target Capsules

Capsule A

Be(Cu) Capsule
Be(Cu2%)
No fill gas
Be
215 μm   10 μm 10 μm 15 μm

Capsule B

Be(Cu) Capsule
Be(Cu2%)
No fill gas
Be
215 μm   20 μm 10 μm 5 μm

Capsule C

Be(Cu) Capsule
Be(Cu2%)
No fill gas
Be
215 μm   10 μm 10 μm 15 μm

Nominal capsule designs have 4 ± 2 μgrams Cu, ~44 μgm Be.

Actual-A and C had higher atom% Cu in BeCu layers and B was near nominal.

No gas in capsules.

The primary purpose of the experiments was to radiographically obtain ablation rate

- Capsule is a "sandwich" of Be(Cu), Be, Be(Cu)
- Be layer opens upon ablation
- Inner Be(Cu) layer provides a velocity fiducial
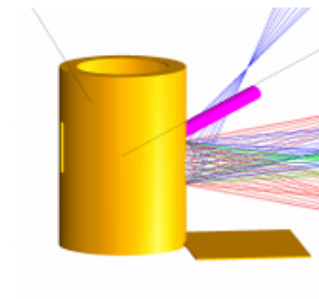

Streaked Radiography Image
1 March 2007

Ablation onset
AT INSIDE OF TRACER

"window" provides
concavity contrast

Dopant for velocity
measurement
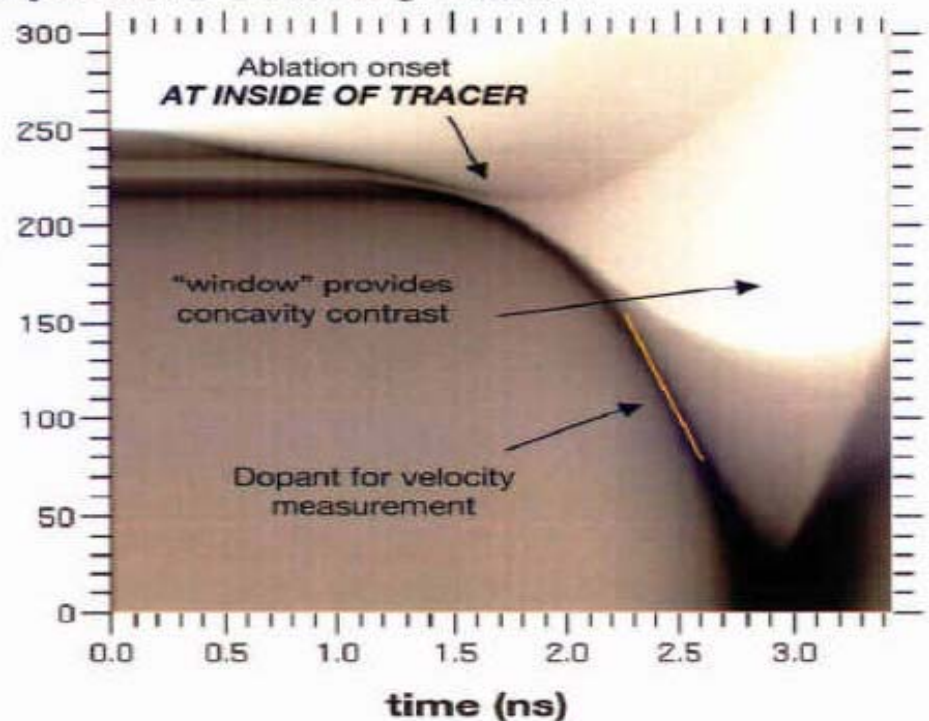
Simulation showing upper half of capsule

Radiochemical samples were collected from two locations in the target chamber

We used semi-conductor quality Si in the flat collector to collect samples

TIM3: Cu-collect

TIM6: Cu-collect
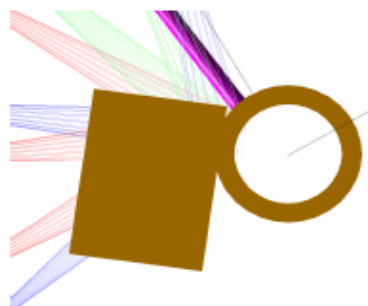
First time we had collected samples on indirect drive shots

We were looking for 10-40 ng of Cu!

- Total Dissolution and ICP-MS analyses
  - Vanadium backlighter ~30 μgm, expect < 1 nanogram Copper added to debris*
  - Gold hohlraum 7mg, will have 35 μgm Au and 6.5 nanogm Cu in debris*
  - BeCu capsules – initial results from meas'd concentrations predict ~430 nanogram Be and 43, 20, or 15 nanogm Cu in debris*
    - A capsule 44 μgm Be, 2.71 at% Cu=8.6 μgm
    - C capsule 41 μgm Be, 1.25 at% Cu=3.9 μgm
    - B capsule 45 μgm Be, 1.33 at% Cu=3.8 μgm

* Assumes 0.5% collection efficiency

Solid samples collected during OMEGA implosions were dissolved

Dissolution chemistry is exciting!

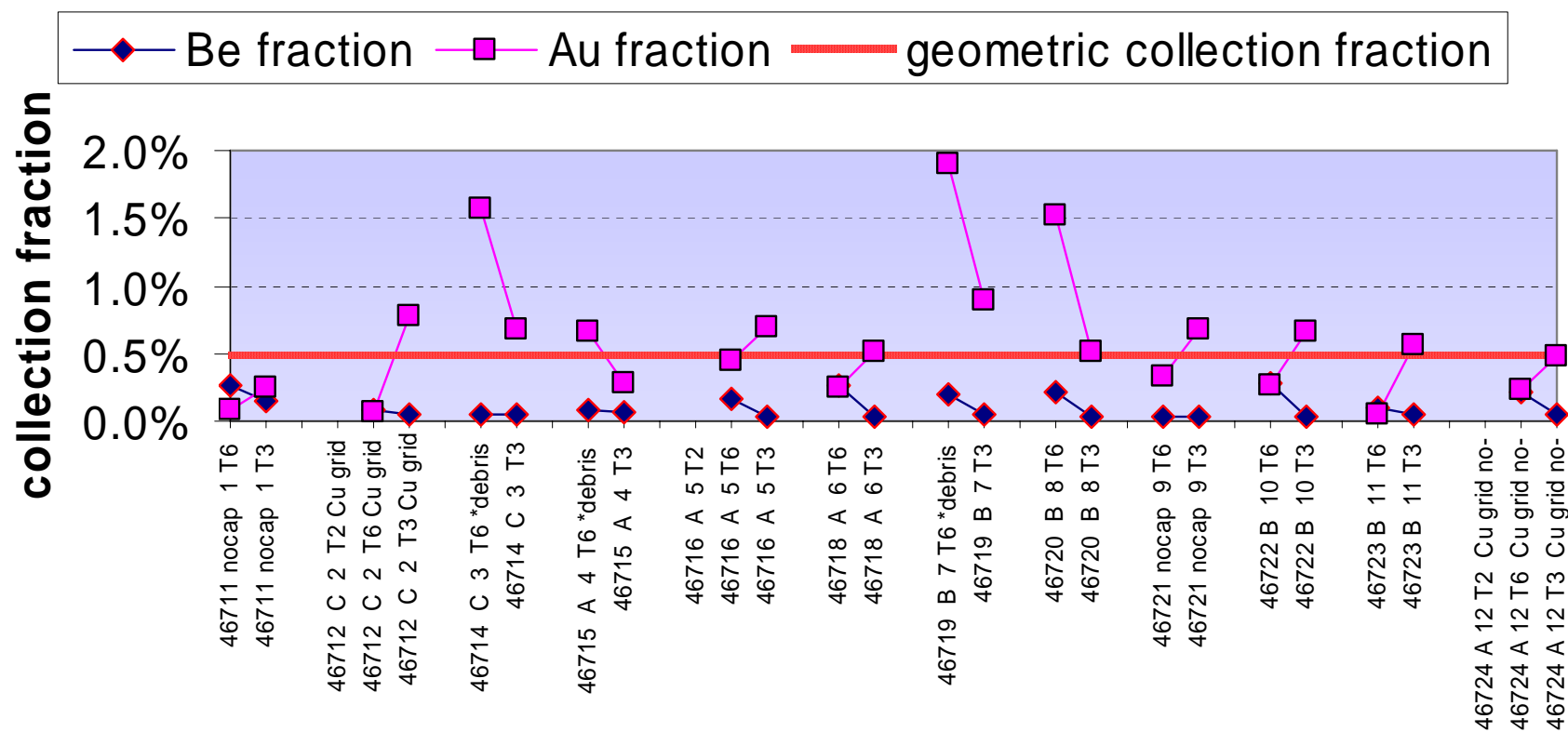Setup for silicon dissolution.

Silicon in acid (HF).

After an addition of HNO_3, exothermic reaction with release of NOx gases.

Near end of dissolution thin, lacy Si pieces, NOx, clear solution and white condensate.

13

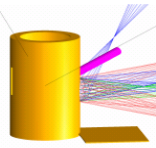# We observed Au and Be above background, but there was a Cu background which obscured our signal
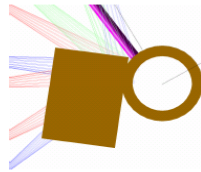

DGH-OCONVAB1 debris

Some observations about Cu collection

- **Appeared to be Cu surface contamination on Si samples**

- **Asymmetry observed in Au and Be collection – more Au collected on collector located on hohlraum waist and more Be collected on collector located at LEH**

- **Easily see the Au, more difficult for Be and Cu was below background—as you would expect from initial amounts of these elements in the experiment**

- **No overwhelming chamber background**

- **Collection trends did not increase from shot to shot during the day indicating small cross-shot contamination**

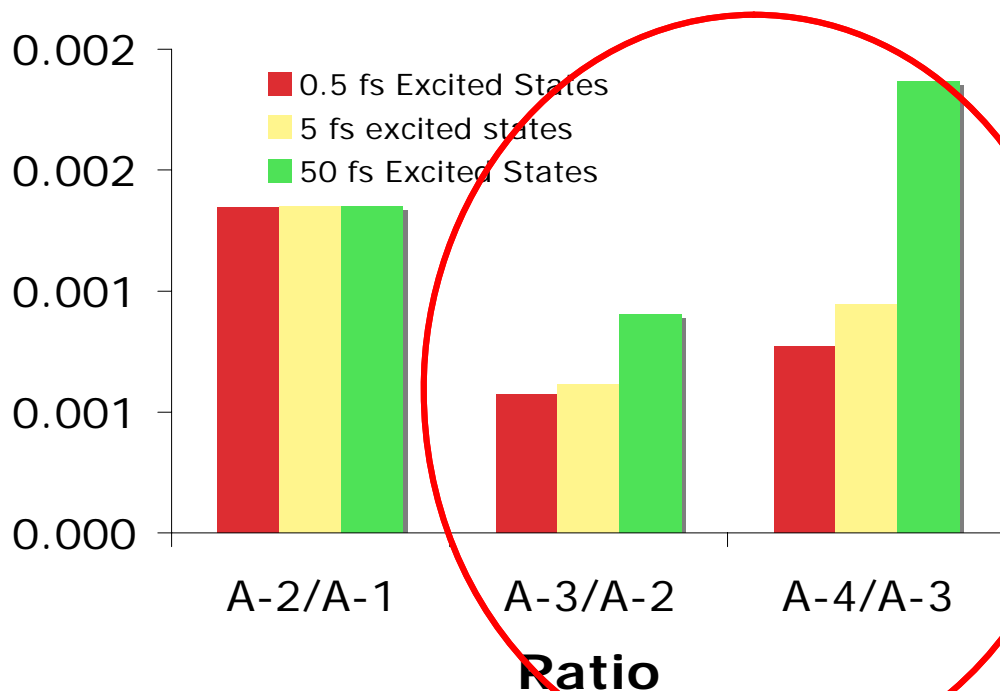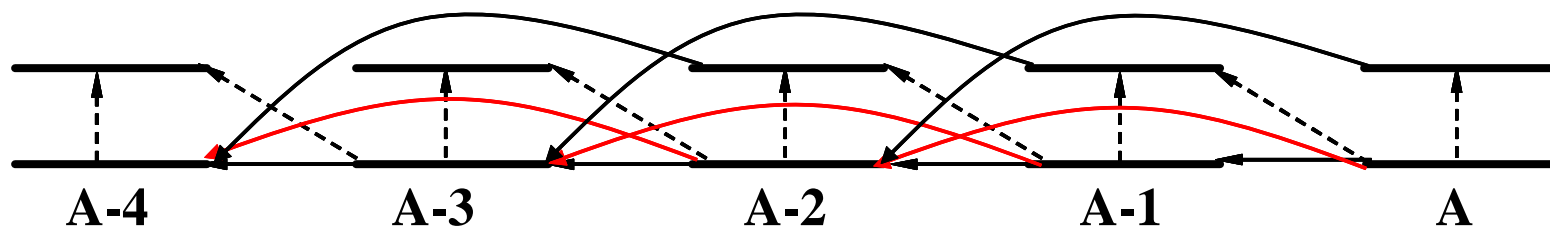# Reactions on excited states could provide insight into reactions on neutron-rich nuclei far from stability*
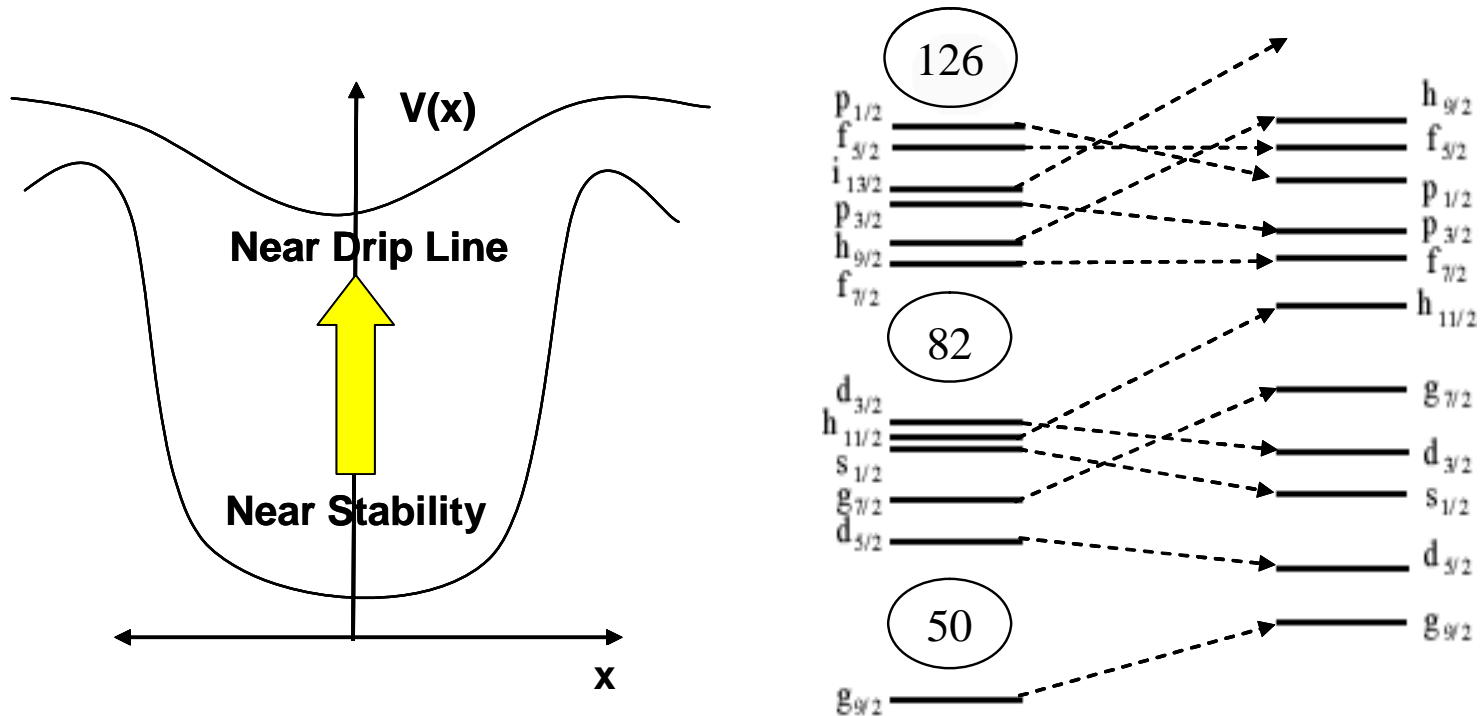
Is shell structure "quenched" in highly excited states?

*L.G. Moretto, U.C. Berkeley

Production of excited states in-situ at NIF does alter the expected radiochemistry product ratios

Toy Radiochemical Model

Reactions on excited states have a clear radiochemical signature

Excited states play a role in the Y cross-section set

Y Cross Section Network...

Legend:
- (n,p),(n,pn) (n,α)
- (n,2n)
- (n,γ)
- (n,n')
- (p,x),(d,x)
- (n,3n)

Nuclides: ⁸⁵Y, ⁸⁶Y, ⁸⁷Y, ⁸⁸Y, ⁸⁹Y, ⁹⁰Y, ⁹¹Y, ⁸⁹Zr